

Capital Adjustment Costs: Implications for Domestic and Export Sales Dynamics*

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November 25, 2012

Abstract

Empirical work on export dynamics has generally assumed constant marginal production cost and therefore ignored domestic product market conditions. However, recent studies have documented a negative correlation between firms' domestic and export sales growth, which suggests that firms are capacity constrained in the short run and face increasing marginal production cost. This paper goes beyond the current literature by developing and estimating a dynamic model of export behavior with capacity constraints and endogenous investment. The model has implications that differ from earlier models that assume constant marginal costs in several respects: (1) in the short run, exporters face trade-off between domestic and export sales. Firms' export sales growth led by positive foreign demand shocks causes a rise in output price and induces welfare losses for domestic consumers. (2): the long-run responses differ from the short-run responses, as firms can adjust their production capacity through capital investment over time.

Using a simulated method of moments approach, I fit the model to plant-level data for Colombian manufacturing industries. The estimated model is used to simulate how the economy transitions in response to an exchange-rate devaluation. The results show that incorporating capital adjustment costs is empirically important. First, it takes more than five years for firms to fully adjust to a permanent change of the exchange-rate process that depreciates the steady state value of the peso by 20%. Second, the long-run and short-run export responses differ: the long-run exchange rate elasticity of exports is 3.46, compared with 2.63 in the short run. Finally, firms' expectation on the duration of the policy changes also matters. The failure to accurately anticipate the duration of the devaluation results in reduction in firms' profits due to over- or under-investment in capital.

*I am grateful to my advisors Jonathan Eaton and James Tybout for their guidance, support and encouragement.

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1 Introduction

How a country's economy transitions following a trade liberalization, change of exchange-rate regime or demand fluctuations have long been of interest to economists, policy-makers and the broader public. While there is little controversy in the argument that trade liberalization and reduction of trade costs increase a country's exports and firm sales, theoretical and empirical work on export responses have generally focused on the long-run effects of these policies and have ignored the short-term consequences. We still lack a good understanding of how the economy transitions from the short-run to the long-run, and how long the transitions lasts.

Studies that focus on long-run export responses have generally been conducted under the assumption that firms face constant marginal production cost. Under this assumption, firms can expand or contract their production capacity freely without incurring any extra costs beyond marginal production cost. This implies that the domestic market is segmented from the export market when firms decide the amount of output to supply in each market in response to external market-specific demand shocks. In particular, when we examine how exports respond to a trade liberalization, this would imply that firms can ramp up their production for the export market with no lags, and the increased export supply does not affect firms' sales and price in the home market. However, recent studies have documented a negative correlation between exporting firms' domestic and export sales growth that challenges the assumption of constant marginal production cost. This is recorded in Blum et al (2011) based on Chilean firm-level data, and in Ahn and McQuoid (2012) based on firm-level data of Indonesian wood industry. This negative correlation between domestic and export sales growth suggests that firms are capacity constrained in the short run. However, in these two papers capacity is fixed and investment in capital is not allowed.¹ As such they cannot characterize the transition of the economy from the short run to the long run in response to a trade liberalization or changes in the exchange-rate regime.

This paper goes beyond the current literature by developing and estimating a dynamic model of firms' sales dynamics in an open economy with capacity constraints and endogenous investment. It incorporates the capital adjustment costs that have been studied typically in the context of a closed economy.² The model has implications that differ from earlier models that assume constant marginal costs in several respects. First, firms that are capacity constrained in the short run face trade-off between domestic and export sales. The increased export sales growth led by positive foreign demand shocks can induce welfare losses

¹In Ahn and McQuoid (2012) only firms that are capacity constrained have fixed capacity. Firms that are not capacity constrained face constant marginal production cost and have unlimited capacity.

²Papers include Caballero and Engel (1999) and Cooper and Haltiwanger (2006), etc.

for domestic consumers as prices increase when firms are capacity constrained. Second, the long-run responses differ from the short-run responses, as firms can adjust their production capacity through capital investment over time. The capital adjustment costs create lagged responses for export and domestic sales in response to external shocks. Finally, firms' expectations about the duration of policy changes or persistence of external shocks affect their sales responses. The failure to accurately anticipate the persistence of shocks results in reduction in profits due to over- or under- investment in capital.

The paper quantifies these effects by fitting the model to plant-level panel data from Colombia. The Colombian data is suited for this study as the empirical evidence suggests firms cannot easily expand or reduce production capacity in the short run.³ It shows that the inability of firms to adjust their production capacity affects their export and domestic sales dynamics. I confirm the substitution behavior between domestic and export sales for exporters as established by other studies. In addition, I document that expansion in the export market is accompanied by an increase in the plant-level price index and high investment level.

The model is estimated using a simulated-method of moments approach. The calibrated model does a good job in replicating the basic features of the Colombian micro data, including the exporting patterns, correlation between domestic and export sales growth among continuing exporters, correlation between export sales and price, the distribution of investment rates, and the serial correlation of investment rates. The estimates of the model suggest that the idiosyncratic demand shocks dominate productivity shocks in generating firms' sales growth. The estimated coefficients for capital adjustment costs suggest both convex and fixed capital adjustment costs exist, and there is substantial price difference in purchasing and selling physical capital.

The calibrated model is then used to conduct policy experiments of changes in the exchange rate regime. The experiment simulates the transitional dynamics of domestic and export sales, price and capital investment from the short run to the long run in response to the policy changes. The results show that incorporating capital adjustment costs is empirically important, and firms' expectation on the duration of the policy changes matters. It takes more than five years for firms to fully adjust to a permanent change of the exchange-rate process that depreciates the steady state value of the peso by 20%. The long-run and short-run export responses differ: the long-run exchange rate elasticity of exports is 3.46, compared with 2.63 in the short run. The findings also include: (1) When firms correctly perceive a temporary currency devaluation, firms substitute their domestic sales towards the export market. There are no responses in capital adjustments. (2) When the devaluation

³This paper uses firm and plant interchangeably.

is temporary but firms incorrectly perceive it to be permanent, firms over-invest in capital and suffer reductions in profit due to increased capital adjustment costs induced by over-investing and downsizing the capital afterward. (3) When the devaluation is permanent but firms incorrectly perceive it to be temporary, firms under-invest in their capacity and the substitution of domestic sales for export sales is prolonged. Firms incur reductions in profit because of the increased marginal cost caused by insufficient capital investment. Domestic consumers also incur welfare losses because of the prolonged periods of high price. (4) When firms correctly perceive permanent currency devaluation, the substitution away from domestic sales for exports is temporary. Firms bring back their domestic sales after they invest in physical capital.

Relation to the Literature This paper is closely related to Blum et al (2011) and Ahn and McQuoid (2012) that also study capacity constraints and export behavior. Both papers provide empirical evidence that supports the view of exporting firms being capacity constrained. Blum et al (2011) document that firms enter and exit the same export destination multiple times, and sell the same products to the same importers upon re-entry. They attribute this behavior to firms facing limited capacity. Ahn and McQuoid (2012) utilize measures such as capital utilization rate and cash flow to asset ratio to identify the financial and physically constrained firms. They document a stronger negative correlation between domestic and export sales growth for the capacity constrained firms than those that are not constrained. In both papers capacity is fixed and investment is not allowed, thus we cannot track the transitional dynamics of domestic and export sales over time after firms relax their capacity constraints.⁴ This paper differs from these two papers in that it develops and estimates a dynamic model with capacity constraints, and the capacity constraints can be relaxed through capital investment over time.

This paper is also related to a broader literature that study export dynamics, including Das et al (2007), Eaton et al (2010), Arkolakis (2010) and Ruhl and Willis (2007, 2008). This paper differs from Eaton et al (2010), Arkolakis (2009, 2010) and Ruhl and Willis (2008) in that it focuses on frictions in the factor market. Ruhl and Willis (2007) looked at labor market frictions, but their focus is on new exporter growth and they ignore the domestic product market. This paper differs from theirs in two ways. 1) It introduces idiosyncratic demand shocks besides productivity shocks. 2) This paper also looks at firms' sales substitution patterns between the domestic and export market, and the correlation between price and sales growth, which are not the focus of Ruhl and Willis (2007).

Another strand of literature that this paper relates to includes research that studies cap-

⁴In Ahn and McQuoid (2012) only firms that are capacity constrained have fixed capacity. Firms that are not capacity constrained face constant marginal production cost and have unlimited capacity.

ital adjustment costs and their implications on the aggregate economy. Caballero and Engel (1999), as well as Cooper and Haltiwanger (2006), have argued that non-convex adjustment costs lead to lumpy investment decisions and aggregate nonlinearity. While these studies focus on a closed economy, this paper explores the implication of capital adjustment costs on domestic and export sales dynamics in the context of an open economy.

The remainder of the paper proceeds as follows: Section 2 presents the structural model. Section 3 provides descriptive analysis of the Colombian plant-level data used in this paper. Section 4 conducts the quantitative analysis that fits the model to the data. Section 5 concludes the paper.

2 Model

The model features a small open economy where exchange rate and foreign market-size are independent of domestic market conditions. It builds on the existing models of firm heterogeneity and exporting. Firms are heterogeneous in terms of both their underlying efficiency and market-specific demand shocks. Exporting to the foreign market entails fixed costs that are paid every period, as in Melitz (2003). Therefore only a fraction of domestic firms export. Firms switch into or out of exporting as they experience demand and productivity shocks, as in Das et al (2007). What this paper adds to these models is a characterization of the relationship between firms' export behavior and their capital formation. Firms are capacity constrained by their capital assets in the short run and face increasing marginal production cost, thus there is a trade-off between the domestic and export sales for exporters. Firms make investment choices given their perception about future market conditions.

The supply side of the model features heterogeneous firms located in the home country with different productivity levels. Each firm produces a single variety using standard Cobb-Douglas technology. The factors of production are labor and physical capital. Labor is variable input that can be freely adjusted at any time, while the amount of physical capital is fixed in the short run. The firms' inability to adjust physical capital in the short run leads to increasing marginal production cost. Over time physical capital can be adjusted through investment but subject to capital adjustment costs.

On the demand side, there is heterogeneous demand for each firm's variety in both the domestic and foreign market. I do not endogenously model demand growth through firms' searching and accumulating customers, or learning about the popularity of their products. This is mainly because I do not observe the necessary demand-side data to do so.

2.1 Demand

The domestic and foreign countries d and f have a continuum of consumers. Consumers in both countries have identical CES preferences with the same elasticity of substitution σ . There is a mass one of varieties available, each produced by a single firm from the domestic country. Consumers in country $k \in \{d, f\}$ have income E_t^k . A representative consumer from country k maximizes its utility

$$U_t^k = \left(\int z_t^k(j)^{\frac{1}{\sigma}} q_t^k(j)^{\frac{\sigma-1}{\sigma}} dj \right)^{\frac{\sigma}{\sigma-1}}, \quad k \in \{d, f\}$$

subject to the budget constraint

$$\int p_t^k(j) q_t^k(j) dj = E_t^k, \quad k \in \{d, f\}$$

where $z_t^k(j)$ is the product appeal of product j at country k , or the weight that consumer in country k place on product j , $q_t^k(j)$ is the demand over variety j from consumers in country k , and $p_t^k(j)$ is variety j 's price at country k ⁵. The demand for product j at country k is

$$q_t^k(j) = z_t^k(j) \frac{p_t^k(j)^{-\sigma}}{(P_t^k)^{1-\sigma}} E_t^k, \quad k \in \{d, f\}$$

where $P_t^k = (\int z_t^k(j) p_t^k(j)^{1-\sigma} dj)^{\frac{1}{1-\sigma}}$. Denote $D_{jt}^k = z_t^k(j) \frac{E_t^k}{(P_t^k)^{1-\sigma}}$, The total demand for variety j from country k is

$$q_{jt}^k = (p_{jt}^k)^{-\sigma} D_{jt}^k, \quad k \in \{d, f\} \quad (1)$$

Note that both foreign price p_{jt}^f and income E_t^f are based on foreign currency here. They are going to be switched to domestic currency when calculate the firm's total revenue.

2.2 Production

On the supply side, each firm produces a single variety and firms compete monopolistically. Firms are heterogeneous in their productivity levels A_{jt} . They employ a Cobb-Douglas production technology with two factors: labor and physical capital. Labor is a variable input so it can be freely adjusted in each period. However, the amount of physical capital in a given period is fixed. The production function for firm j at time t is

$$q_{jt} = A_{jt} K_{jt}^{\alpha_k} L_{jt}^{\alpha_l}$$

⁵Firm j and product j are used interchangeably because each firm produces only one variety.

Given firm j 's capital level K_{jt} , wage w , its marginal production cost as a function of its output q_{jt} is:

$$MC_{jt} = \frac{w}{r_2} q_{jt}^{\frac{1}{\alpha_l} - 1} A_{jt}^{-\frac{1}{\alpha_l}} K_{jt}^{-\frac{\alpha_k}{\alpha_l}} \quad (2)$$

The total variable production cost is

$$TVC_{jt} = w q_{jt}^{\frac{1}{\alpha_l}} A_{jt}^{-\frac{1}{\alpha_l}} K_{jt}^{-\frac{\alpha_k}{\alpha_l}} \quad (3)$$

Marginal cost MC_{jt} is therefore an increasing function of its total output q_{jt} as long as the labor share α_l is less than 1. In addition, the higher the firm's productivity A_{jt} and capital level K_{jt} , the lower its marginal production cost is.

2.3 Static problem

In the beginning of each period, a firm observes its productivity and demand shock in both the domestic and foreign market. Given its capital level, the firm chooses its output, whether to export or not, and if so, the allocation of its output in the domestic and foreign market.

Exporting entails a per-period fixed cost f , therefore only firms with productivity or foreign demand above a certain level exports. Denote η_{jt} as the share of its total production that is sold abroad, so $q_{jt}^f = \eta_{jt} q_{jt}$. I solve the problem in two steps: (1) Given a firm's output q_{jt} , a firm decides its export share η_{jt} if it exports. (2) Given the optimal export share if it exports, a firm decides the optimal output q_{jt} and whether to export or not. Based on the demand function (1), the firm's total revenue in domestic currency if it exports is

$$\begin{aligned} S(A_{jt}, K_{jt}, D_{jt}^d, D_{jt}^f, e_t) &= \max_{\eta_{jt} \in [0,1]} p_{jt}^d (1 - \eta_{jt}) q_{jt} + e_t p_{jt}^f \eta_{jt} q_{jt} \\ &= \max_{\eta_{jt} \in [0,1]} \left[(1 - \eta_{jt})^{\frac{\sigma-1}{\sigma}} (D_{jt}^d)^{\frac{1}{\sigma}} + e_t (\eta_{jt})^{\frac{\sigma-1}{\sigma}} (D_{jt}^f)^{\frac{1}{\sigma}} \right] (q_{jt})^{\frac{\sigma-1}{\sigma}} \end{aligned}$$

Here e_t denotes the exchange rate: 1 unit of foreign currency worth e_t domestic currency at time t .

We can solve for the optimal export share η_{jt} by maximization of the above equation.

The optimal η_{jt} for an exporting firm is

$$\begin{aligned}\eta_{jt}^* &= \left(1 + \frac{D_{jt}^d}{D_{jt}^f e_t^\sigma}\right)^{-1} \\ \frac{q_{jt}^f}{q_{jt}^d} &= \frac{D_{jt}^f e_t^\sigma}{D_{jt}^d} \\ \frac{p_{jt}^f}{p_{jt}^d} &= \frac{\left(\frac{q_{jt}^f}{D_{jt}^f}\right)^{-\frac{1}{\sigma}}}{\left(\frac{q_{jt}^d}{D_{jt}^d}\right)^{-\frac{1}{\sigma}}} = \frac{1}{e_t}\end{aligned}$$

p_{jt}^f is the price a firm charges abroad in foreign currency, therefore we can denote a firm-level price in domestic currency:

$$p_{jt} = e_t p_{jt}^f = p_{jt}^d \quad (4)$$

This property relies on the assumption that the demand elasticity is the same for both domestic and foreign consumers. Under this assumption firms do not price discriminate across markets. The optimal export share η_{jt}^* only depends on the demand shocks and the exchange rate, but not on the total output level. So essentially the firm faces a world-wide demand and charges the same price. Denote $x_{jt} \in \{0, 1\}$ as an indicator of firm j being an exporter or not, with $x_{jt} = 1$ indicating that firm j exports. Define $D_{jt} = D_{jt}^d + (D_{jt}^f e_t^\sigma) \cdot 1(x_{jt} = 1)$, equivalently,

$$D_{jt} = \begin{cases} (D_{jt}^d + D_{jt}^f e_t^\sigma), & \text{if export: } x_{jt} = 1 \\ D_{jt}^d, & \text{if not export: } x_{jt} = 0 \end{cases}$$

The optimal export share implies the revenue for the firm becomes

$$S^{x_{jt}}(A_{jt}, K_{jt}, D_{jt}^d, D_{jt}^f, e_t) = (D_{jt})^{\frac{1}{\sigma}} (q_{jt})^{\frac{\sigma-1}{\sigma}}$$

Given the revenue a firm can potentially get by selling to both markets at any given output level, the firm decides whether to export or not and the amount to produce by solving the problem below:

$$\max_{q_{jt}, x_{jt} \in \{0, 1\}} S^{x_{jt}}(A_{jt}, K_{jt}, D_{jt}^d, D_{jt}^f, e_t) - TVC(A_{jt}, K_{jt}, q_{jt}) - f \cdot 1(x_{jt} = 1)$$

The optimization problem implies the optimal quantity to produce, revenue and total variable

cost to be:

$$\begin{aligned}
q_{jt} &= \left\{ \frac{\sigma-1}{\sigma} \frac{w}{\alpha_l} (A_{jt} K_{jt}^{\alpha_k})^{\frac{1}{\alpha_l}} (D_{jt})^{\frac{1}{\sigma}} \right\}^{\frac{1}{\frac{1}{\alpha_l} - \frac{\sigma-1}{\sigma}}} \\
S(A_{jt}, K_{jt}, D_{jt}^d, D_{jt}^f, e_t) &= \left(\frac{\sigma-1}{\sigma} \frac{\alpha_l}{w} \right)^{c_1} (D_{jt})^{c_2} \left((A_{jt} K_{jt}^{\alpha_k})^{\frac{1}{\alpha_l}} \right)^{c_3} \\
TVC(A_{jt}, K_{jt}, D_{jt}^d, D_{jt}^f, e_t) &= w \left(\frac{\sigma-1}{\sigma} \frac{\alpha_l}{w} \right)^{1+c_1} (D_{jt})^{c_2} \left((A_{jt} K_{jt}^{\alpha_k})^{\frac{1}{\alpha_l}} \right)^{c_3}
\end{aligned}$$

where $c_1 = \frac{1}{\alpha_l} \frac{1}{\frac{1}{\alpha_l} - \frac{\sigma-1}{\sigma}}$, $c_2 = \frac{1}{\sigma} \frac{1}{\alpha_l} \frac{1}{\frac{1}{\alpha_l} - \frac{\sigma-1}{\sigma}}$, $c_3 = \frac{\sigma-1}{\sigma} \frac{1}{\frac{1}{\alpha_l} - \frac{\sigma-1}{\sigma}}$. The superscript x_{jt} which indicates the export status is omitted, as it is captured in the aggregate demand shock: $D_{jt} = D_{jt}^d + (D_{jt}^f e_t^\sigma) \cdot 1(x_{jt} = 1)$. Note that the productivity and demand shocks, capital enter the revenue and total variable cost function in the same way, thus total variable cost is a fraction of a firm's total revenue:

$$\frac{TVC(A_{jt}, K_{jt}, D_{jt}^d, D_{jt}^f, e_t)}{S(A_{jt}, K_{jt}, D_{jt}^d, D_{jt}^f, e_t)} = \frac{\sigma-1}{\sigma} \alpha_l \quad (5)$$

Therefore a firm's per-period profit is:

$$\Pi^{x_{jt}}(A_{jt}, K_{jt}, D_{jt}^d, D_{jt}^f, e_t) = \left(1 - \frac{\sigma-1}{\sigma} \alpha_l\right) S(A_{jt}, K_{jt}, D_{jt}^d, D_{jt}^f, e_t) - f \cdot 1(x_{jt} = 1)$$

Firm j chooses to export if the profit from selling in both market is greater than that from selling in the domestic market alone:

$$\Pi^{x_{jt}=1}(A_{jt}, K_{jt}, D_{jt}^d, D_{jt}^f, e_t) - \Pi^{x_{jt}=0}(A_{jt}, K_{jt}, D_{jt}^d, D_{jt}^f, e_t) > 0 \implies x_{jt} = 1$$

2.4 Dynamic Problem

The problem is dynamic because a firm's current investment decision affects its future capital stock and production capacity. The state variables include capital stock K_{jt} , productivity A_{jt} , firm specific demand shocks D_{jt}^d, D_{jt}^f , and the exchange rate e_t . Capital stock K_{jt} is the only endogenous state variable and the rest are exogenous. An incumbent producer in the domestic market chooses the capital investment to maximize the value of continuing

operating in the market:

$$\begin{aligned}
V(A_{jt}, K_{jt}, D_{jt}^d, D_{jt}^f, e_t) = & \tag{6} \\
& \max_{I_{jt}} \Pi(A_{jt}, K_{jt}, D_{jt}^d, D_{jt}^f, e_t) - \Lambda(I_{jt}, K_{jt}) \\
& + \frac{1}{1+r} EV(A_{jt+1}, (1-\delta)K_{jt} + I_{jt}, D_{jt+1}^d, D_{jt+1}^f, e_{t+1} | A_{jt}, D_{jt}^d, D_{jt}^f, e_t)
\end{aligned}$$

where $K_{jt+1} = (1 - \delta)K_{jt} + I_{jt}$. $\Lambda(I_{jt}, K_{jt})$ is the associated capital adjustment costs. The functional form for $\Lambda(I_{jt}, K_{jt})$ is provided in section 2.6. $\frac{1}{1+r}$ is the discount rate for next period's profits. The value function is comprised of the current profit and discounted future profits net of the capital adjustment costs associated with the investment.

Note that export status is not a state variable here because there is no sunk entry cost for new exporters. For simplification the entry and exit into production are not modeled.

2.5 Functional Forms

To solve the model numerically, the log of productivity A_{jt} , idiosyncratic demand shocks D_{jt}^d, D_{jt}^f and real exchange-rate are assumed to follow independent first-order autoregressive processes:

$$\begin{aligned}
\ln A_{jt} &= m_a + \rho_a \ln A_{jt-1} + \varepsilon_{jt}^a \\
\ln D_{jt}^d &= m_d + \rho_d \ln D_{jt}^d + \varepsilon_{jt}^d \\
\ln D_{jt}^f &= m_f + \rho_f \ln D_{jt}^f + \varepsilon_{jt}^f \\
\ln e_t &= m_e + \rho_e \ln e_{t-1} + \varepsilon_t^e
\end{aligned}$$

where $\varepsilon_{jt}^a \sim i.i.d.N(0, \sigma_{\varepsilon^a}^2)$, $(\varepsilon_{jt}^d, \varepsilon_{jt}^f) \sim i.i.d.N(0, (\sigma_{\varepsilon^d}^2, \sigma_{df}\sigma_{\varepsilon^d}\sigma_{\varepsilon^f}; \sigma_{df}\sigma_{\varepsilon^d}\sigma_{\varepsilon^f}, \sigma_{\varepsilon^f}^2))$, $\varepsilon_t^e \sim i.i.d.N(0, \sigma_{\varepsilon^e}^2)$. σ_{df} allows the innovations to the domestic and foreign demand shocks to be correlated. Given these functional forms, the expected future value $EV(\cdot | A_{jt}, D_{jt}^d, D_{jt}^f, e_t)$ in the value function can be parameterized.

2.6 Capital Adjustment Costs

The evolution of firm j 's capital stock follows

$$K_{jt+1} = (1 - \delta)K_{jt} + I_{jt}$$

where δ is the depreciation rate and I_{jt} is the capital investment. The investment rate, $i_{jt} = \frac{I_{jt}}{K_{jt}}$ can be either positive or negative. There is one-period time-to-build, so investment made at period t becomes effective at period $t + 1$.

In addition to the time to build assumption, adjusting the capital stock is costly. The capital adjustment cost function is specified as:

$$\Lambda(I_{jt}, K_{jt}) = \frac{\lambda_1}{2} \left(\frac{I_{jt}}{K_{jt}} \right)^2 K_{jt} + \lambda_2 1(|\frac{I_{jt}}{K_{jt}}| > 0) K_{jt} + I_{jt} 1(I_{jt} > 0) - \lambda_3 I_{jt} 1(I_{jt} < 0) \quad (7)$$

The adjustment costs include a quadratic cost $\frac{\lambda_1}{2} \left(\frac{I_{jt}}{K_{jt}} \right)^2 K_{jt}$ that is usually assumed in traditional investment models, a fixed cost of adjustment λ_2 , and transaction costs λ_3 that captures a gap between the buying and selling price of capital. This specification is close to that of Cooper and Haltiwanger (2006).⁶ The convex costs dampens the investment responses to shocks and lead to partial adjustment of investment. The fixed cost of adjustment $\lambda_2 K_{jt}$ is independent of the level of investment. It is proportional to the level of capital to eliminate any size effect. Compared with partial adjustment implied by the convex costs, the fixed adjustment costs imply frequent investment inactivity and investment spikes. The price gap between purchasing and selling capital would also dampen firms' investment responses to positive productivity or demand shocks, as selling the capital in the future would incur a loss. In addition, the price gap imply that firms will hold on to capital in response to a negative shock.

3 Data

The data used in this paper is from Departamento Administrativo Nacional de Estadística (DANE). It covers plants with more than ten employees from year 1981 to 1991. I merged two datasets: one is used in Roberts and Tybout (1997) and the other is used in Eslava et al (2004). The first one contains plant level information including both domestic sales and export sales, plants' capital and investment in different capital categories, and other plant characteristics. The extra information from the dataset that is used in Eslava et al (2004) is a price index for plants' output at the plant-level. Though we do not observe the domestic and foreign price separately for exporting plants, in the CES model under the assumption that demand elasticities are the same at home and abroad, the foreign price and domestic price collapse into one price, as shown in equation (4) in the model section.

⁶The only difference is that Cooper and Haltiwanger (2006) incorporates an additional type of non-convex adjustment cost that represents a loss of a fraction of the output during the adjustment period. Since their implications are similar to the fixed adjustment costs, I only keep the fixed adjustment costs for simplification.

This price index provides useful information to separately identify the productivity and demand processes. Also the price responses to shocks reveal how easily firms can adjust their production capacity.

As the focus of the paper is the sales and capital adjustment of an existing plants, I keep a balanced sample by dropping the plants that enter or exit the panel in the middle of the sample period. This leaves a total number of 2235 plants for 11 years. I keep 19 major exporting industries in the Colombian manufacturing sector, as in Roberts and Tybout (1997).⁷

3.1 Empirical Evidence

Below I present key features of the data that characterize the transitional dynamics of domestic and export sales, plant-level price and physical capital. These features suggest that plants cannot easily expand or reduce production capacity in the short run, with some plants being capacity constrained and others having excess capacity. The data features include the following: 1) There is substitution between domestic and export sales among exporters. 2) The expansion in the export market is accompanied by an increase in the plant-level price index. 3) The sales substitution and export expansion is followed by a high investment level and capital growth. 4) Plants that substitute away from the domestic market towards the foreign market in the previous period bring back their domestic sales later after capital is adjusted. I discuss these features in detail below.

The key feature that suggests plants cannot easily adjust their production capacity in the short run is the substitution between exporters' domestic and export sales. Substitution between domestic and foreign sales happens when two conditions are satisfied: (1) plants receive a more favorable demand shock in one market relative to the other. (2) it is costly for plants to adjust their production capacity. The sales substitution across markets is shown by a negative correlation between firms' domestic and export sales growth rate. Here export and domestic sales growth are defined as:

$$\frac{\Delta S_{jt}^f}{S_{jt}^t} = \frac{S_{jt}^f - S_{jt-1}^f}{\frac{1}{2}(S_{jt}^t + S_{jt-1}^t)}$$

$$\frac{\Delta S_{jt}^d}{S_{jt}^t} = \frac{S_{jt}^d - S_{jt-1}^d}{\frac{1}{2}(S_{jt}^t + S_{jt-1}^t)}$$

⁷The 19 industries are: food processing, textiles, clothing, leather products, paper, printing, chemicals, plastic, glass, nonmetal products, iron and steel, metal products, machinery, transportation equipment, and miscellaneous manufacturing.

S_{jt}^f , S_{jt}^d , and S_{jt}^t indicate a plant's export, domestic and total sales separately. The export sales growth rate for plant j at year t is calculated as the difference of export sales between year t and $t - 1$ divided by the mean total sales between year t and $t - 1$, and similarly for domestic sales growth. The growth rates for domestic and export sales are both weighted by the total sales so they are comparable.

Figure 1.1 plots the mean domestic sales growth rate for plants grouped based on their export sales growth. It shows that plants that expand significantly in the export market reduce their domestic sales even though their total sales grow, suggesting those plants can be capacity constrained. On average a plant with export sales growth around 20% decreases its domestic sales by 5%, and that with export sales growth greater than 50% decrease domestic sales by 20%. In contrast, plants that contract their export sales increase their domestic sales even though their total sales decline. Figure 1.1 shows that a plant with export sales growth $\frac{\Delta S_{jt}^f}{S_{jt}^t}$ around -30% increases its domestic sales by 14%. The conjecture is that these plants suffer a bad demand shock in the foreign market. They temporarily reallocate their output away from the foreign market towards the domestic market because it's costly to reduce the production capacity.

In addition to the sales substitution patterns, changes in the plant-level price provide further support for those plants either being capacity constrained or having excess capacity. Price growth $\frac{\Delta p_{jt}}{p_{jt}}$ is defined as:

$$\frac{\Delta p_{jt}}{p_{jt}} = \frac{p_{jt} - p_{jt-1}}{\frac{1}{2}(p_{jt} + p_{jt-1})}$$

If plants are capacity constrained, namely, the level of output fails to keep up pace with demand, price should go up. To the contrary, if plants have excess capacity and output is beyond the market demand, then price should fall. Figure 1.2 presents the price changes consistent with this view. For the plants that expand in the export market and decrease their domestic sales which suggest them being capacity constrained, we also see an increase in the plant-level price. It shows that plants with export sales growth above 30% increase their price by around 7%. On the contrary, we observe a price decrease for the plants that contract their export sales and increase domestic sales. Figure 1.2 shows that plants with export sales growth $\frac{\Delta S_{jt}^f}{S_{jt}^t}$ around -30% decrease their price by 8%.

Plants' adjustments in capital in response to the sales substitution and price changes are summarized in Figure 1.3. It shows that those plants that are suggested to be capacity constrained have high capital growth rate $GK_{i,t}$ in the subsequent period. Capital growth rate is defined as $GK_{i,t} = \frac{K_{i,t} - K_{i,t-1}}{0.5 \cdot (K_{i,t-1} + K_{i,t})}$. The plants with export sales growth around 30% increase their capital by 15% in the following period. On the contrary, those plants that are

believed to have excess capacity, have near zero or negative capital growth rate. The fact that we do not see much negative capital growth rate partly reflects the irreversibility of capital, that is, there is a price gap between buying and selling the capital. Therefore firms may choose to hold on to instead of selling the capital in response to negative shocks.

Figure 1.4 shows that the negative correlation of domestic and export sales growth in the short run is reversed over time as plants adjust their production capacity. Compared with a negative correlation of domestic and export sales growth shown in Figure 1.4, we observe a positive correlation between the export sales growth and the subsequent-year domestic sales growth. In particular, those plants that substitute their domestic sales towards the foreign market in the previous year, have a faster growth in domestic sales than that of an average plant in the following year. As shown in Figure 1.1, the plants with export sales growth greater than 50% decrease their domestic sales by 20% at the same year, but in the following years, their domestic sales grows by 7%. This suggests these previously capacity-constrained plants bring up their output by investing in capital, as shown in figure 1.3. On the other hand, those plants that have excess capacity reduce their output in the subsequent year. As shown in Figure 1.4, the plants with export sales growth around -30%, increase domestic sales by 14% at the same year, but in the following years, their domestic sales decrease by 4%.

In summary, the empirical evidence above supports the argument that the inability for plants to freely adjust their production capacity in the short run induces substitution behavior between plants' domestic and export sales, as well as the corresponding price changes. It also shows that plants adjust their production capacity through capital investment over time, which leads to a different correlation between domestic and export sales compared with that in the short run.

4 Quantitative Analysis

4.1 Fitting the Model to Data

In fitting the model to data, I calibrate the parameters of the model to replicate features of Colombian micro data. First, The real-exchange rate process is estimated using the real exchange-rate series. Second, the production function parameters are calibrated based on the wage share of firms. I also fix some parameters at values reported by previous studies. Finally, the remaining parameters are estimated to match a set of moments based on firm-level behavior.

4.1.1 Pre-determined parameters

Table 1 summarizes the parameters that are set or estimated without solving the model. Some standard parameters are fixed at values reported by previous studies. First, the real borrowing rate r is set to be 0.15 (Bond et al. 2008). The depreciation rate of capital δ is set to be 7%. The elasticity of substitution is σ is set to be 3.5, which is within the range that is typical of the literature. The mean of log productivity is normalized to be 0.

The coefficients for the real exchange-rate process is obtained from Das et al (2007), where they fit an AR(1) process to the log of the real effective exchange-rate series for the Colombian peso, 1968-1992. The coefficients (standard errors in parentheses) are $m_e = 0.549(0.429)$, $\rho_e = 0.883(0.094)$, and $\sigma_{\epsilon_e}^2 = 0.0043$. The exchange rate parameters are treated as fixed in solving the model to estimate the remaining the parameters.

The labor share α_l in the production function is determined based on the equation which states that the wage cost is a fixed share of the total revenue: $\frac{TVC_{jt}}{R_{jt}} = \frac{\sigma-1}{\sigma}\alpha_l$. Given that the mean wage cost share is 0.51 in the Colombian micro-data⁸, and σ is set to be 3.5, we can back out the labor share α_l to be 0.72. The capital share is determined by assuming constant return to scale, therefore $\alpha_k = 1 - \alpha_l = 0.28$. The constant term $\frac{\sigma-1}{\sigma}\frac{\alpha_l}{w}$ that appears in the revenue function, is normalized to be 1.

Table 1: Parameters set without solving the model

Parameter	Description	Value
α_k	capital share in production function	0.28
α_l	labor share in production function	0.72
σ	elasticity of substitution	3.5
m_a	drift of log productivity process	0
m_e	drift of log exchange-rate process	0.549
ρ_e	persistence of log exchange-rate process	0.883
$\sigma_{\epsilon_e}^2$	variance of innovation of log exchange-rate	0.0043

4.1.2 Remaining Parameters

The remaining parameters of interest are estimated using a simulated method of moments approach (a description of the computation algorithm is provided in the appendix). There are thirteen parameters remain to be determined: parameters that govern the evolution of the idiosyncratic domestic and foreign demand shocks: $m_d, \rho_d, \sigma_{\epsilon^d}$ and $m_f, \rho_f, \sigma_{\epsilon^f}, \sigma_{df}$, coefficients for the log productivity process: ρ_a and σ_{ϵ^a} , fixed cost of exporting f , and parameters that govern the capital adjustment cost: the coefficient for the quadratic adjustment

⁸In calculating wage cost share, I use the value added instead of total sales.

costs λ_1 , coefficient for the fixed adjustment cost λ_2 , and the selling price for investment λ_3 . Fitting the model to the data involves estimating the parameters to fit the following thirteen targets (listed in table 2): fraction of plants that export, export turnover rate, mean export-to-total-sale ratio, new exporter survival rate, correlation between export and domestic sales growth for all continuing exporters, correlation between current export sales growth and subsequent domestic sales growth, correlation between export sales and price growth, autocorrelation of plants' log domestic sales, autocorrelation of log total sales, fraction of plants with investment spike, fraction of plants with investment inaction, fraction of plants with negative investment, and the autocorrelation of plants' investment rate.

While there is no one-to-one mapping between individual parameters and individual statistics, certain statistics respond more to particular parameters and thus help to identify these parameters. First, identification of the parameters of the capital adjustment costs function λ_1, λ_2 and λ_3 mainly depend on the investment and capital growth patterns at the plant level. These parameters directly affect the distribution of capital growth rate. The selling price for capital, λ_3 , affects the fraction of plants with negative investment rate. High values of the coefficient for fixed adjustment costs, λ_2 , creates investment spikes and inaction at the plant level. Instead, if the convex adjustment costs governed by λ_1 dominates, there is more small adjustment of capital and less investment spikes and inaction. Therefore the fraction of plants with investment spikes, investment inaction and negative investment rate are informative. The auto-correlation of investment rate $Corr(i_{jt}, i_{jt-1})$ is sensitive to the type of adjustment cost. In the absence of capital adjustment costs, the autocorrelation of investment rate is negative because of the AR(1) process of productivity and demand shocks. Under convex adjustment cost, plants adjust capital partially and it leads to a positive investment autocorrelation. It worth noting the distribution and persistence of investment rate also depend on the exogenous shock processes for demand and productivity.

Table 2: Data-based versus Simulated Moments[†]

Moment	Data	Model	Moment	Data	Model
Fraction of plants that export	0.20	0.19	$Corr(i_{j,t}, i_{j,t-1})^{\ddagger}$	0.02	0.09
Export turnover rate	0.14	0.27	investment spike: $\%(i_{j,t} > 0.4)^*$	0.23	0.19
Export-sales ratio	0.21	0.29	investment inaction: $\%(i_{j,t} < 0.03)$	0.36	0.39
New exporter survival rate	0.65	0.59	negative investment: $\%(i_{j,t} < -0.03)$	0.05	0.17
$Corr(\frac{\Delta S_{jt}^f}{S_{jt}^t}, \frac{\Delta S_{jt}^d}{S_{jt}^t}) _{\text{exporters}^*}$	-0.15	-0.14			
$Corr(\frac{\Delta S_{jt}^f}{S_{jt}^t}, \frac{\Delta S_{jt+1}^d}{S_{jt+1}^t}) _{\text{exporters}^*}$	0.06	0.15	$Corr(\log S_{jt}^d, \log S_{jt+1}^d)$	0.93	0.94
$Corr(\frac{\Delta S_{jt}^f}{S_{jt}^t}, \frac{\Delta p_{jt}}{p_{jt}}) _{\text{exporters}^*}$	0.12	0.22	$Corr(\log S_{jt}^t, \log S_{jt+1}^t)$	0.97	0.95

[†]: the metric for model fit is $\|M^{data} - M^{simulated}\| / \|M^{data}\| = 0.162$, where M^{data} is the vector of data-based moments, $M^{simulated}$ is the vector of simulated moments, and $\|\cdot\|$ is the Euclidean distance norm.

*: exporters include those that export at both period t and period $t + 1$.

[‡]: investment rate $i_{j,t} = I_{jt}/K_{jt}$, where I_{jt}, K_{jt} are the investment and capital level at time t .

*: the moment is the fraction of plant-year observations with investment rate greater than 40%.

Table 3: Estimated Parameter Values

Parameter	Description	Value
m_d	drift of log domestic demand	0.24
ρ_d	persistence of log domestic demand	0.87
σ_{ϵ^d}	std of innovation of log domestic demand	0.81
m_f	drift of log foreign demand	-0.40
ρ_f	persistence of log foreign demand	0.89
σ_{ϵ^f}	std of innovation of log foreign demand	1.22
σ_{df}	correlation for innovations of log domestic and foreign demand	0.1
ρ_a	persistence of log productivity	0.88
σ_{ϵ^a}	std of innovation of log productivity	0.16
f	export fixed cost	1.6
λ_1	coefficient on convex adjustment costs	0.0002
λ_2	coefficient on fixed adjustment costs	0.0002
λ_3	selling price of investment	0.80

Second, there are parameters that governs the demand $\rho_d, \sigma_{\epsilon^d}$ and $\rho_f, \sigma_{\epsilon^f}, \sigma_{df}$, and those govern the productivity processes ρ_a and σ_{ϵ^a} . One statistic that is sensitive to these parameters is the correlation between domestic and export sales growth for continuing exporters $\text{Corr}\left(\frac{\Delta S_{jt}^f}{S_{jt}^t}, \frac{\Delta S_{jt}^d}{S_{jt}^t}\right)$. Productivity growth drives up sales in both the domestic and foreign markets, which leads to a positive $\text{Corr}\left(\frac{\Delta S_{jt}^f}{S_{jt}^t}, \frac{\Delta S_{jt}^d}{S_{jt}^t}\right)$. On the contrary, demand growth could generate negative correlation between domestic and foreign sales growth when plants cannot freely adjust their production capacity. In addition, the correlation between plant-level price index and sales growth further helps to separate the demand and productivity process. This is because when a plant receives a positive productivity shock, its sales go up and price goes down as production cost falls. On the contrary, if a plant receives a positive demand shock, both sales and price are driven up. The target moment I use is the correlation between export sales growth and price growth $\text{Corr}\left(\frac{\Delta S_{jt}^f}{S_{jt}^t}, \frac{\Delta p_{jt}}{p_{jt}}\right)$. A positive correlation between sales and price growth gives more weight to demand variation, while a negative one favors productivity variation. The autocorrelation for log domestic sales $\text{Corr}(\log S_{jt}^d, \log S_{jt+1}^d)$, autocorrelation for log total sales $\text{Corr}(\log S_{jt}^t, \log S_{jt+1}^t)$ are also informative about the persistence of demand and productivity processes.

Finally, the fraction of firms that exports is very responsive to fixed exporting cost f : a lower fixed exporting cost encourages more firms to export. The mean export-to-total-sales ratio is very responsive to the drift of the log domestic and foreign demand m_d and m_f . A higher $\frac{m_f}{m_d}$ implies a higher export share for exporting firms. Export turn-over rate and survival rate for new exporters respond to the persistence of the productivity and demand shocks: a high persistence of the shocks leads to low export turn-over rate and high survival rate for new exporters.

Table 2 reports the data-based statistics that the model targets to match, and their model-based simulated counterparts. The simulated model does a good job in matching the correlation between the domestic and export sales growth for continuing exporters, which represents the short-run trade-off between domestic and export sales when firms are capacity constrained. It captures the autocorrelation of log domestic sales and log total sales. It also fits well the fraction of plants with investment inaction and spikes.

It is also worth noting that a few moments are not matched very precisely. First, there is slightly higher export turn-over rate and lower survival rate for new exporter in the simulated model than in the data. This potentially can be improved by introducing sunk export entry cost for new exporters. Second, the export-sales ratio in the model is also slightly over-predicted. This is because in the data there are a lot of firms exporting a very small share of their output (less than 1 percent) which is not captured in the model. The correlation

between export growth and price growth, and the correlation between current export sales growth and the subsequent domestic sales growth are also slightly over-predicted in the model. Finally, the fraction of plants with negative investment rate is higher in the model than that in the data.⁹

Table 3 reports the parameters associated with the estimation. The coefficients for the adjustment costs imply both convex and fixed adjustment costs exist, and there is sizable gap between buying and selling the capital. These parameters are close to what Cooper and Haltiwanger (2006) obtain in calibrating their model to the U.S. economy. The implied variance suggests demand fluctuation dominates productivity fluctuation in generating plants' sales variation. This is consistent with the sales substitution patterns between domestic and exporter sales among exporters.

4.2 Simulated Effect of a Devaluation

I simulate firms' responses to a change in the exchange-rate process that depreciates the steady state value of the peso by 20%.¹⁰ It is implemented by increasing the intercept of the log exchange rate process m_e from 0.549 to 0.572, while keeping the persistence and variance of the innovation term unchanged. The regime shifts take place in the middle of the sample period t_m . There are four scenarios: (I): Correctly-perceived temporary devaluation: the currency devaluation lasts only one period and firms have the correct expectations. (II): Incorrectly-perceived temporary devaluation: the currency devaluation lasts only one period, but firms incorrectly perceive it as permanent. Firms correct their expectation in the following period $t_m + 1$. (III): Incorrectly-perceived permanent devaluation: the currency devaluation is permanent, but firms thought it lasts only one period. They correct their expectation in the subsequent period $t_m + 1$. (IV): Correctly-perceived permanent devaluation: the currency devaluation is permanent, and firms have the right expectations. Under all four scenarios the shift of exchange-rate regime was not expected before it takes place at period t_m .

Short-run and Long-run Exchange Rate Elasticity of Exports

How exports respond to the exchange rate devaluation is of particular interest to this paper. The importance of capital adjustment costs in affecting the export responses is

⁹While this statistics is affected by the price gap between purchasing and selling the capital, it is also affected by the fraction of plants that receive negative productivity and demand shocks.

¹⁰Alternatively we can look at reduction of trade costs or increase in foreign demand. These policies would have similar effects as changes in the exchange-rate process, as the model assumes that the real exchange rate only affects the effective price paid by foreign consumers and thus foreign demand. Since the model does not separately identify the trade cost from foreign demand, reduction in trade cost and increase in foreign demand are equivalent.

reflected by different exchange rate elasticities of exports in the short run and long run. Its importance is also seen in how long it takes to have the export responses fully realized. Here I only focus on scenario IV where the devaluation is permanent and firms have the correct expectations. The other three scenarios are of more interest when we look at the transitional dynamics of sales, investment and output price in the following section.

Figure 2 summarizes the transition of the accumulated aggregate export sales following the permanent shift of the exchange-rate regime. I focus on the growth rate of the accumulated aggregate export sales after the devaluation, relative to that in the base case.

$$\widehat{S}_{\tilde{t}} = \frac{\left(\sum_{t=t_m}^{\tilde{t}} S_t^f \right)^{\text{counter-factual}} - \left(\sum_{t=t_m}^{\tilde{t}} S_t^f \right)^{\text{base}}}{\left(\sum_{t=t_m}^{\tilde{t}} S_t^f \right)^{\text{base}}}$$

where $\sum_{t=t_m}^{\tilde{t}} S_t^f$, the accumulated aggregate export sales at time \tilde{t} , is the sum of aggregate export sales from the devaluation period t_m to \tilde{t} : $\sum_{t=t_m}^{\tilde{t}} S_t^f = \sum_{t=t_m}^{\tilde{t}} \sum_j S_{jt}^f$. While the immediate export response is big, there is still substantial adjustments in the subsequent years. The accumulated aggregate export sales increase by 70% right after the devaluation takes place at t_m . The growth rate keeps rising over time, particularly during the first two or three years after the devaluation. It stabilizes after about five years. The accumulated aggregate export sales has doubled 5 years after the permanent devaluation.

Figure 3 shows that the exchange rate elasticity of exports has increased from 2.63 at t_m to 3.46 five years after.¹¹ Similarly, the exchange rate elasticity of exports rises fast during the first three years after the devaluation takes place, and it stabilizes about five years after. The exchange rate elasticity of exports at \tilde{t} is calculated as the change of the log of accumulated export sales from the base case to after the devaluation, compared the base case, divided by the change in the log real exchange rate.

$$\xi_{\tilde{t}} = \frac{\left(\ln \sum_{t=t_m}^{\tilde{t}} S_t^f \right)^{\text{counter-factual}} - \left(\ln \sum_{t=t_m}^{\tilde{t}} S_t^f \right)^{\text{base}}}{(\ln e)^{\text{counter-factual}} - (\ln e)^{\text{base}}}$$

¹¹The short-run exchange rate elasticity of exports are the same in other three scenarios, regardless the duration of the devaluation and firms' expectations. When the devaluation is temporary and being correctly perceived (scenario I), the long-run exchange rate elasticity of exports converges to zero because there is no export growth after period t_m .

Transitional Dynamics of Investment, Output Price, Domestic and Export sales

The effects on domestic and export sales, investment and prices under each scenario, relative to a base case of no regime change, are summarized in table 4. Table 4 focuses on the adjustments on the intensive margin (among incumbents), so it limits to the exporters that export in period $t_m, t_m + 1, t_m + 2$ in the base case. I compare the aggregate domestic sales for those incumbent exporters in three years following the devaluation, relative to the base case weighted by the average aggregate total sales. The change in investment is weighted by the aggregate capital. In terms of the price change after the devaluation, I look at the average price change among the incumbent exporters. Note that here the changes are year-by-year, not accumulative. The changes in domestic and foreign sales, investment and price for each scenario, in each of the three years following in the experimental devaluation are defined as:

$$\begin{aligned} \frac{\Delta S_t^d}{\overline{S_t^{total}}} &= \frac{\sum_{j \in E} (S_{jt}^d)^{\text{counter-factual}} - \sum_{j \in E} (S_{jt}^d)^{\text{base}}}{0.5 \left(\sum_{j \in E} (S_{jt}^{total})^{\text{counter-factual}} + \sum_{j \in E} (S_{jt}^{total})^{\text{base}} \right)} \\ \frac{\Delta S_t^f}{\overline{S_t^{total}}} &= \frac{\left(\sum_{j \in E} S_{jt}^f \right)^{\text{counter-factual}} - \left(\sum_{j \in E} S_{jt}^f \right)^{\text{base}}}{0.5 \left(\left(\sum_{j \in E} S_{jt}^{total} \right)^{\text{counter-factual}} + \left(\sum_{j \in E} S_{jt}^{total} \right)^{\text{base}} \right)} \\ \frac{\Delta I_t}{\overline{K_t}} &= \frac{\left(\sum_{j \in E} I_{jt} \right)^{\text{counter-factual}} - \left(\sum_{j \in E} I_{jt} \right)^{\text{base}}}{0.5 \left(\left(\sum_{j \in E} K_{jt} \right)^{\text{counter-factual}} + \left(\sum_{j \in E} K_{jt} \right)^{\text{base}} \right)} \\ \frac{\Delta p_t}{\overline{p_t}} &= \frac{1}{N(E)} \sum_{j \in E} \frac{(p_{jt})^{\text{counter-factual}} - (p_{jt})^{\text{base}}}{0.5 \left((p_{jt})^{\text{counter-factual}} + (p_{jt})^{\text{base}} \right)} \end{aligned}$$

In all four scenarios, at period t_m when the devaluation takes place, incumbent exporters substitute their domestic sales towards export sales and price goes up. The aggregate export sales for the incumbent exporters increase by 18.3% compared with that the base case, while domestic sales decrease by 3.6%. The mean price has increased by 6.0%. Foreign demand increases as the domestic-produced products become cheaper for foreign consumers after the devaluation. As the marginal production cost increases on total output given the fixed amount of capital in the short run, firms sacrifice their sales at home to meet up the increased demand in the foreign market. It induces welfare losses for domestic consumers as price goes up.

However, firms' investment responses $\frac{\Delta I_t}{K_t}$ at t_m differ depending on their perception about the duration of the devaluation. In scenario II and IV where firms expect the exchange-rate process to be permanent, firms expand their production capacity in response: the aggregate investment for the incumbent exporters increase by 25.2% as a share of their total capital. In contrary, in scenario I and IV where firms expect the exchange-rate process to move back to the base case in the following period, there are no changes in the investment level for the incumbent exporters compared with the base case.

The corresponding investment adjustment at t_m in each scenario directly impact firms' sales and output prices in the subsequent periods, especially for scenario II and III where there is misperception about the duration of the devaluation. In scenario II, the incumbent exporters over-invest in capital at t_m as they thought the devaluation is permanent while it lasts only one period. Therefore in the subsequent period $t_m + 1$ as foreign demand falls back to the level of the base case, firms have excess production capacity. As a result, price falls by 6.3%, and both domestic and export sales are higher than their counterparts in the base case. The aggregate investment decrease by 8.2% at period $t_m + 1$, showing that they are reducing their excess capacity. The investment and price reduction, as well as the sales rise continue at period $t_m + 2$, but the magnitude is smaller. Note that the size of capital reduction in the subsequent periods is lower than the capital expansion made in period t_m , as firms tend to hold up to their capital in response to a negative shock because of the price gap between purchasing and selling the capital. The increased capital adjustment costs induced by over-investing and downsizing the capital afterward cause profit reductions for these exporters.

In contrast to the over-investment in capital in scenario II, in scenario III the incumbent exporters under-invest in their capital as they mistakenly expect the devaluation to be temporary while it is actually permanent. As a result, the substitution from domestic sales towards export sales, and the price rise are prolonged. Firms remain to be capacity constrained in period $t_m + 1$: domestic sales decrease by 3.4% at period $t_m + 1$ relative to the base case. Output prices keep rising as output continues to be falling behind the demand: the mean price for the incumbent exporters' products rise by 6.1%. This increased price leads to welfare losses for domestic consumers. As firms correct their expectations about the duration of the devaluation in period $t_m + 1$, they increase their capital investment. As a result, in period $t_m + 2$, they bring back their domestic sales and price stops rising: domestic sales increase by 2.8% in period $t_m + 2$. The inadequate capital investment induced by firms' misperception causes profits reductions for firms and welfare losses for domestic consumers.

When firms correctly perceive the permanent currency devaluation in scenario IV, the substitution away from domestic sales for export sales is temporary. After they increase the

capital investment at period t_m , the incumbent exporters bring back their domestic sales in period $t_m + 1$: domestic sales increase by 1.9%. There is a greater response in export sales: aggregate export sales increase by 25.3% in $t_m + 1$, which shows that the frictions in adjusting firms' production capacity generate lagged responses. Price falls slightly and aggregate investment in $t_m + 1$ increase by 8.1% suggesting firms make partial adjustments in capital. In period $t_m + 2$ sales continue to grow, but in a smaller magnitude. At last, in scenario I where firms correctly perceive the temporary devaluation, the economy moves back to the base case after the temporary sales substitution and price rise at period t_m .

Table 4: Effects of a devaluation for incumbent exporters

Scenario I: correctly-perceived temporary devaluation				Scenario II: incorrectly-perceived temporary devaluation			
	period t_m	t_m+1	t_m+2		period t_m	t_m+1	t_m+2
$\frac{\Delta S_t^d}{S_t^{total}}$	-3.6%	0%	0%	$\frac{\Delta S_t^d}{S_t^{total}}$	-3.6%	6.0%	2.7%
$\frac{\Delta S_t^f}{S_t^{total}}$	18.3%	0%	0%	$\frac{\Delta S_t^f}{S_t^{total}}$	18.3%	6.1%	1.8%
$\frac{\Delta S_t^{total}}{S_t^{total}} \dagger$	14.7%	0%	0%	$\frac{\Delta S_t^{total}}{S_t^{total}}$	14.7%	12.1%	4.5%
$\frac{\Delta I_t}{K_t}$	0%	0%	0%	$\frac{\Delta I_t}{K_t}$	25.2%	-8.2%	-4.8%
$\frac{\Delta p}{\bar{p}}$	6.0%	0%	0%	$\frac{\Delta p}{\bar{p}}$	6.0%	- 6.3%	- 3.5%
Scenario III: incorrectly-perceived permanent devaluation				Scenario IV: correctly-perceived permanent devaluation			
	period t_m	t_m+1	t_m+2		period t_m	t_m+1	t_m+2
$\frac{\Delta S_t^d}{S_t^{total}}$	-3.6%	-3.4%	2.8%	$\frac{\Delta S_t^d}{S_t^{total}}$	-3.6%	1.9%	4.6%
$\frac{\Delta S_t^f}{S_t^{total}}$	18.3%	17.5%	16.8%	$\frac{\Delta S_t^f}{S_t^{total}}$	18.3%	25.3%	18.0%
$\frac{\Delta S_t^{total}}{S_t^{total}}$	14.7%	14.1%	19.6%	$\frac{\Delta S_t^{total}}{S_t^{total}}$	14.7%	27.2%	22.6%
$\frac{\Delta I_t}{K_t}$	0%	19.4%	-0.1%	$\frac{\Delta I_t}{K_t}$	25.2%	8.1%	-3.6%
$\frac{\Delta p}{\bar{p}}$	6.0%	6.1%	-0.6%	$\frac{\Delta p}{\bar{p}}$	6.0%	-0.2%	-3.1%

†: changes in aggregate total sales $\frac{\Delta S_t^{total}}{S_t^{total}} = \frac{\Delta S_t^d}{S_t^{total}} + \frac{\Delta S_t^f}{S_t^{total}}$ as $\frac{\Delta S_t^d}{S_t^{total}}$, $\frac{\Delta S_t^f}{S_t^{total}}$ are weighted by the total sales.

5 Conclusion

In this paper I develop and estimate a dynamic structural model of export dynamics with capacity constraints and endogenous investment. The model features increasing marginal production cost and capital adjustment costs. The short-run capacity constraints imply that

exporters face a trade-off between domestic and export sales in response to external demand shocks. It also implies that firms' export sales growth led by positive foreign demand shocks causes a rise in output price and induces welfare losses for domestic consumers. As firms can adjust their production capacity through capital investment over time, the long-run responses differ from the short-run responses.

Using a simulated method of moments approach, I fit the model to plant-level data for Colombian manufacturing industries. The estimates suggest that the idiosyncratic demand shocks dominate productivity shocks in generating firms' sales growth. The estimates also show that both convex and fixed capital adjustment costs exist, and there is substantial price difference in purchasing and selling physical capital.

The resulting model is used to conduct policy experiments of changes in the exchange-rate regime. I quantify firms' responses in different scenarios where the shift in the exchange-rate regime can either be temporary or permanent, and firms may or may not accurately anticipate the duration of the exchange-rate regime shift. The results show that incorporating capital adjustment costs is empirically important. It takes more than five years for firms to fully adjust to a permanent change of the exchange-rate process that depreciates the steady state value of the peso by 20%. The long-run and short-run export responses differ: the long-run exchange rate elasticity of exports is 3.46, compared with 2.63 in the short run.

The fact that there are costs in adjusting capital also makes expectations matter. In the short run, firms' responses are the same regardless of the expectations and the duration of the policy: incumbent exporters sacrifice their domestic sales to meet up the increased foreign demand after a devaluation, and output prices goes up. However investment responses differ in different scenarios and directly impact firms' sales growth in the long run: (1) when the exchange-rate regime shift is permanent but firms thought it is temporary, exporters under-invest in their capital and the substitution of domestic sales for export sales is prolonged. Firms incur profit losses because of the increased marginal cost caused by insufficient capital investment. Domestic consumers also incur losses because of the prolonged periods of high price. (2) When the regime shift is temporary but firms inaccurately anticipated it to be permanent, exporters over-invest in capital and suffer reductions in profit due to increased capital adjustment costs induced by over-investing and downsizing the capital afterward.

6 Figures

Figure 1: Patterns on domestic and export sales, capital and output price

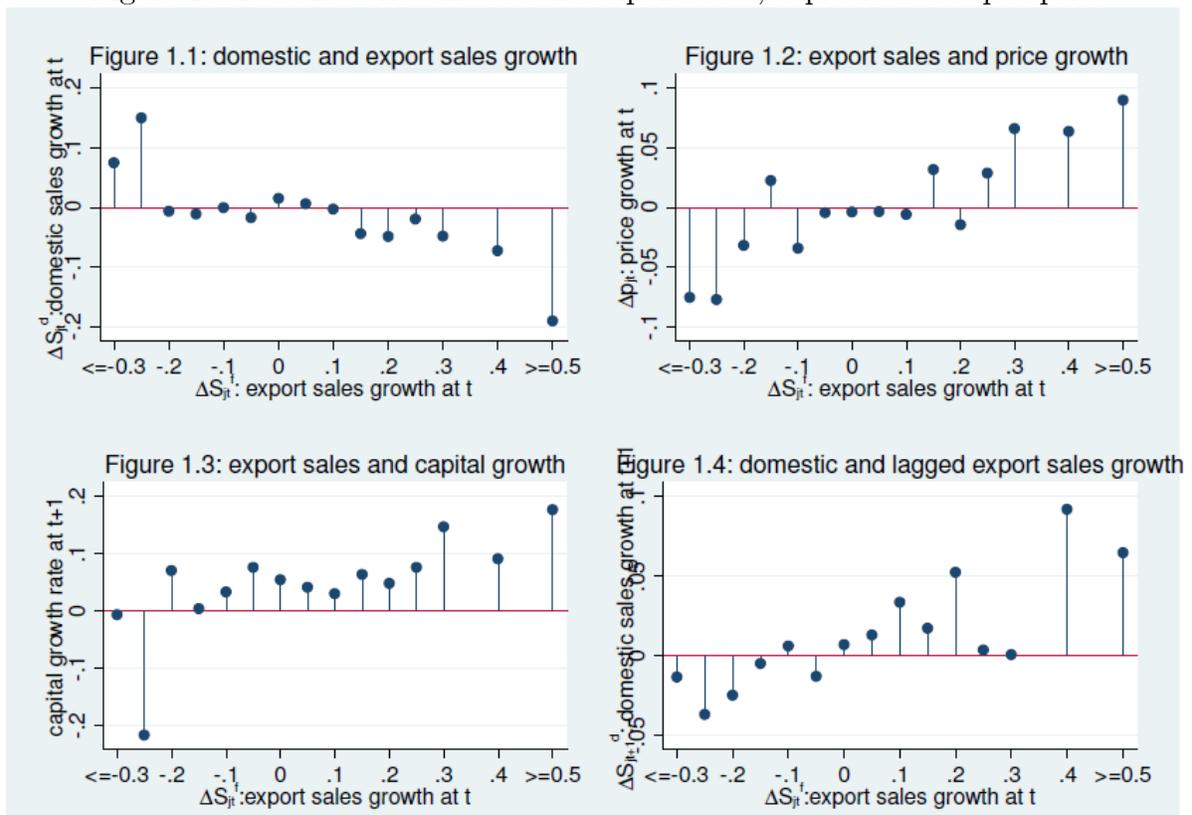


Figure 2:

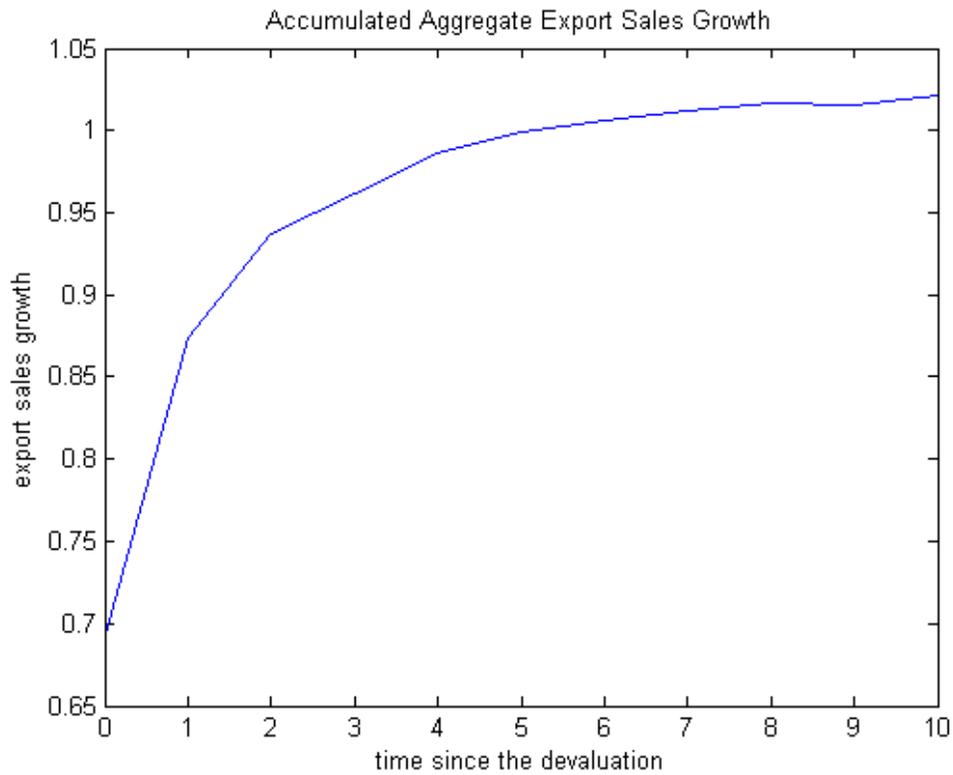


Figure2: Growth Rate of Accumulate Aggregate Export Sales

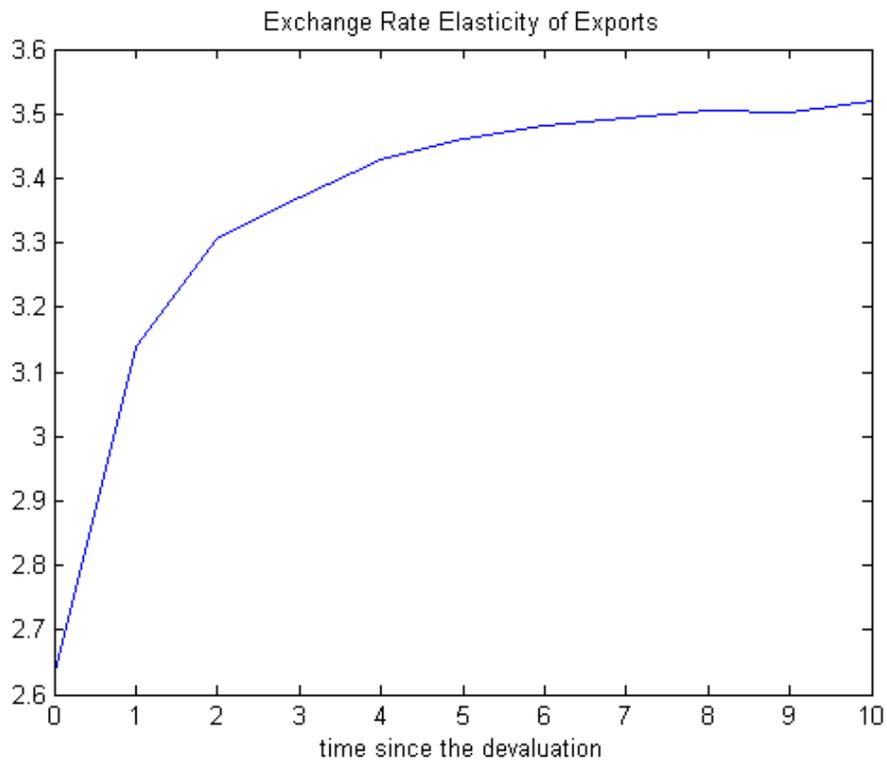


Figure 3: Short-run and Long-run Exchange Rate Elasticity of Exports

7 Appendix: Numerical Solution Algorithm

This appendix describes the computational details of the algorithm used in the estimation. Denote Θ as the vector of parameters to be estimated. The estimation follows the following routine:

- (1) For a given value of Θ , solve the dynamic problem of firms, captured by the value function described in section 2.4. This step yields the value and policy functions for the firms.
- (2) Using the policy functions, simulate the decisions for a panel of S firms for T periods. Calculate a set of moments from the simulated data.
- (3) Update Θ based on the distance between the simulated moments and the data moments.

Step 1. To solve the Bellman equation below,

$$\begin{aligned} & V(A_{jt}, K_{jt}, D_{jt}^d, D_{jt}^f, e_t) \\ = & \max_{I_{jt}} \Pi(A_{jt}, K_{jt}, D_{jt}^d, D_{jt}^f, e_t) - \Lambda(I_{jt}, K_{jt}) \\ & + \frac{1}{1+r} EV(A_{jt+1}, (1-\delta)K_{jt} + I_{jt}, D_{jt+1}^d, D_{jt+1}^f, e_{t+1} | A_{jt}, D_{jt}^d, D_{jt}^f, e_t) \end{aligned}$$

first I use Tauchen's method to discretize the state space for the continuous state variables including productivity A_{jt} , capital K_{jt} , domestic and foreign demand shocks D_{jt}^d, D_{jt}^f and exchange rate e_t . Following section 2.3, I compute the per-period revenue, output and export choices at each state in the grid. Capital investment is the only dynamic choice. It is determined as a firm maximizes the sum of its current and discounted future profits. The value function is iterated, and it stops when a certain convergence criterion is met.

Step 2. Using the policy functions from step 1, I simulate the decisions for a panel of 2000 firms for 20 periods. Firms' idiosyncratic productivity and demand shocks are simulated following the specified AR(1) processes, and mapped to the grids of the state space respectively. The shocks in the initial period are drawn from the steady-state distribution implied by the AR(1) processes. Firms' decisions follow the policy functions described in step 1. The moments specified in Table 2 are calculated from the simulated data. The first 10 periods are considered as burn-in periods and not used to calculate the data moments. The moments depend on Θ in a nonlinear way.

Step 3. Steps 1 and 2 together generate the moments of interest for any given Θ . In step 3, Θ is updated to minimize a weighted distance between the data moments and the simulated moments. The minimization is performed using the genetic algorithm.

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